A New Scheme for

Producing Bright Proton Bunches in MI for Tevatron shots

Chandra Bhat

Run II Meeting

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Acknowledgements:

Jim MacLachlan, Bill Foster, Dave Wildman, Dave Johnson,
Valeri Lebedev and Vladimir Shiltsev

Ref.: Fermilab-FN-0761-AD

Motivation

The instantaneous luminosity at each experiment is given by

$$L = \frac{\gamma}{2\pi} f_0 B N_p N_{pbar} \frac{H}{\beta^* \varepsilon_p \left\{ 1 + \frac{\varepsilon_{pbar}}{\varepsilon_p} \right\}}$$

Design goal → 2.7×10^{32} $cm^{-2}sec^{-1}$ (~a factor of 3 over current average)

Increasing N_p and N_{pbar} and,
decreasing ε s and longitudinal emittances { Produce higher instantaneous luminosity.

Plans for Pbars: "2.5MHz pbar Acceleration"-Combination of 2.5MHz and 53MHz Acceleration (2.5MHz Acceleration from 8GeV -27 GeV, harmonic transfer from h=28→h=588, 53MHz acceleration from 27GeV-150 GeV) being commissioned

Protons

The present 150 GeV coalescing scheme **has done SUPERB JOB** providing intense proton beam to the Tevatron Collider Runs over the past two decades.

Present Status:

- From MI: ~270E9 ppb per coalesced bunch with
  RMS bunch length ≈ 2.3 nsec ⇒ LE≈ 2.5 eVs (MISBD)(95%)
- In Tevatron at Collision: ~225E9 ppb with
  <LE> < 3 eVs (TevSBD).

  (Causes for beam loss: MI→Tev transfer, 150 GeV lifetime, Acceleration in Tev, low beta-squeeze)

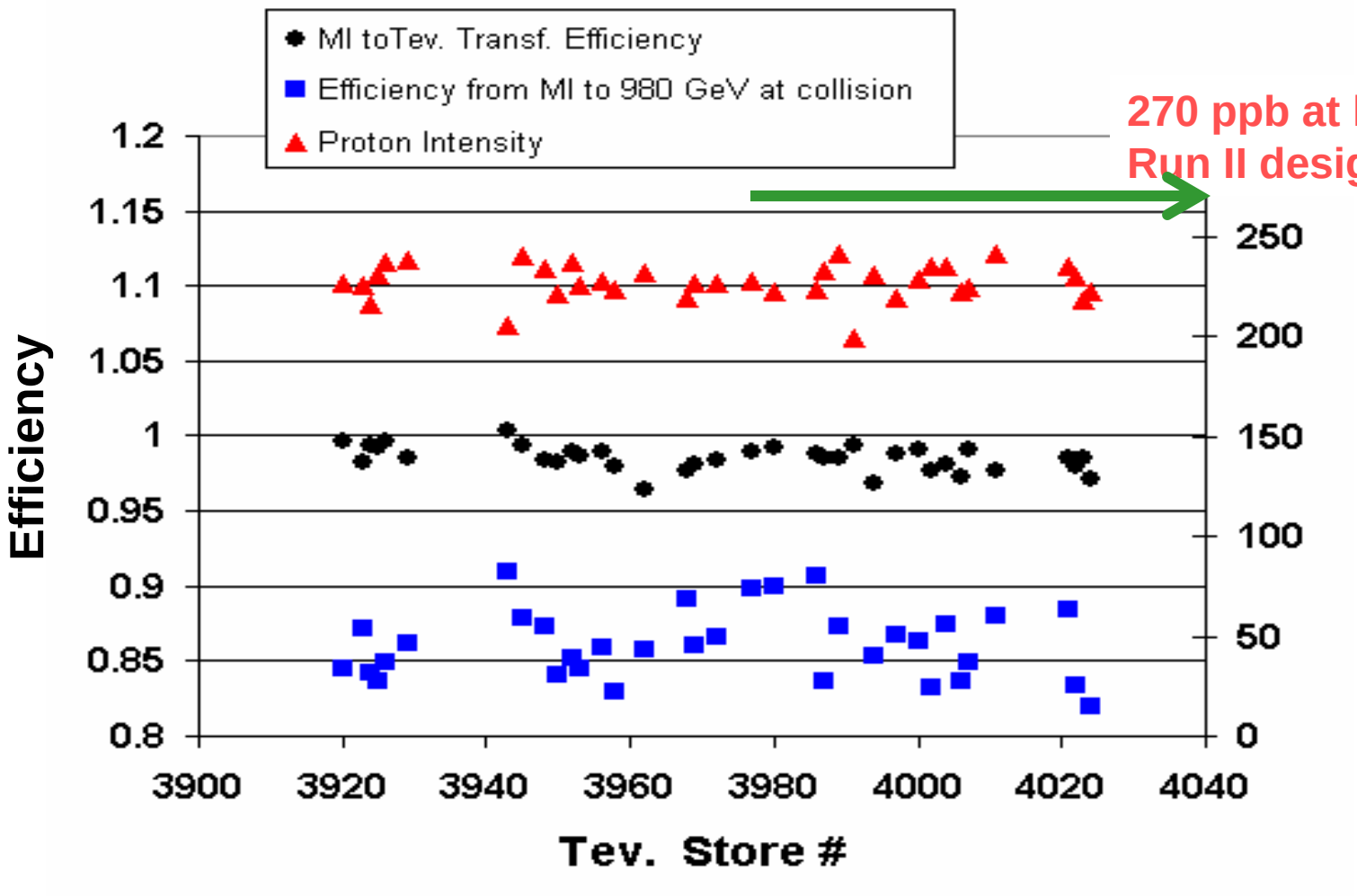
This implies – about 20% lower luminosity because of beam loss and 2% from the Hourglass factor due to large LE at collision.

Tevatron study showed that if proton LE is reduced from 3 eVs to 2 eVs keeping the other beam properties same we can improve the peak luminosity by about 12-17%.

Can we improve the quality of the proton beam in the MI?

Yes!

Proton Bunch Intensity at collision and Proton efficiencies



From Vladimir Shiltsev Beams-doc-1585-v2, Feb. 18, 2005

Next Three Months: Expectations

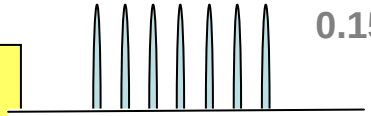
- Over the next 3 months, I expect:
  - stable operation at 90-100 e30, combined shots
  - D0 luminosity monitor fixed (→+6% in AVG lumi)
  - less study time as reliability improves
  - possible improvements
    - 10-20% increase in proton intensity with ~same emittance
    - 5-10% more pbars from RR ← smaller Emm, 120mA stash
    - 5-10% lumi-lifetime improvements← WPs, octupoles, etc
    - β* 35→ 28 cm studies to start and may be even cashed in
- As the result, I expect peak CDF luminosity to be around 120-130e30 by May 1, 2004 ~~4~~ 5

Present scheme

Current Bunch Coalescing Scheme

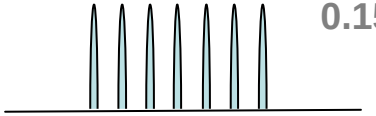
WCM data

8GeV
53MHz Bunches



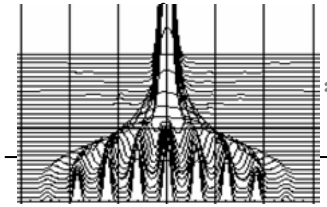
0.15 eVs /53MHz Bunches

150GeV (BC)
53MHz Bunches



0.15 eVs /53MHz Bunches

150 GeV (AC)
53MHz bunches



≈2.5 eVs /53MHz Bunches

LE ≥2.5 eVs with
270 E9p/bunch

Demand:

≈ 270 E9p/53MHz with LE< 2.5 eVs at collision

One can get higher bunch intensity by coalescing more bunches, but, LE becomes >3 eVs.

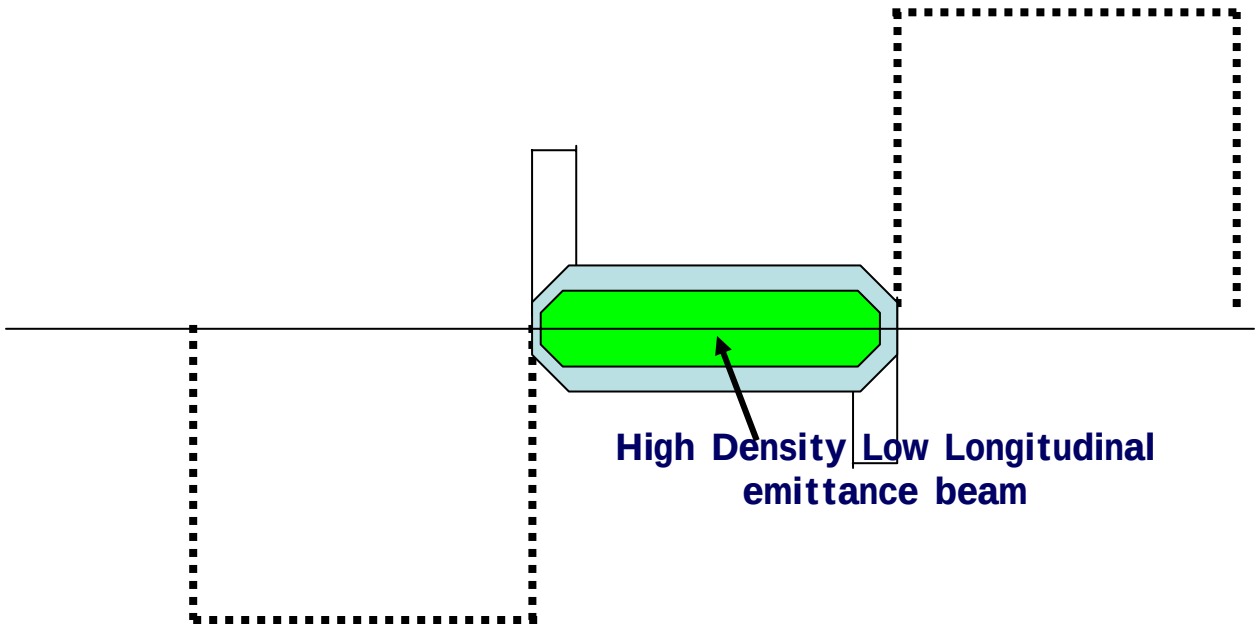
Schemes for Producing Brighter Proton Bunches

- Coalescing at 25-40 GeV -- C. A. Rodríguez and C. Bhat (2000)
- A Scheme for bunch formation for the Tevatron collider – G. Jackson ← 8 GeV bunch formation (2002)
- Thoughts on using MI Broad-band rf system to produce high intensity proton bunches
  ← Bill Foster, C. Bhat
  (independently)

Schemes I'm proposing here:

- Barrier Bucket Scheme-1
  - Barrier coalescing + longitudinal momentum mining
- Barrier Bucket Scheme-2
  - Barrier compression + longitudinal momentum mining

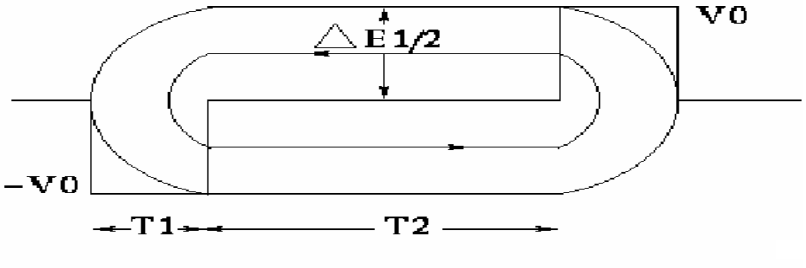
Principle of the Barrier Bucket Scheme-1



We plan to do these rf manipulations above the MI transition energy (20.49 GeV)

What sets the properties of the of the final Bunch?

(Properties of Barrier Buckets)



Properties of the small Barrier
Voltage Vo
Pulse Width T1
Pulse Gap T2 and

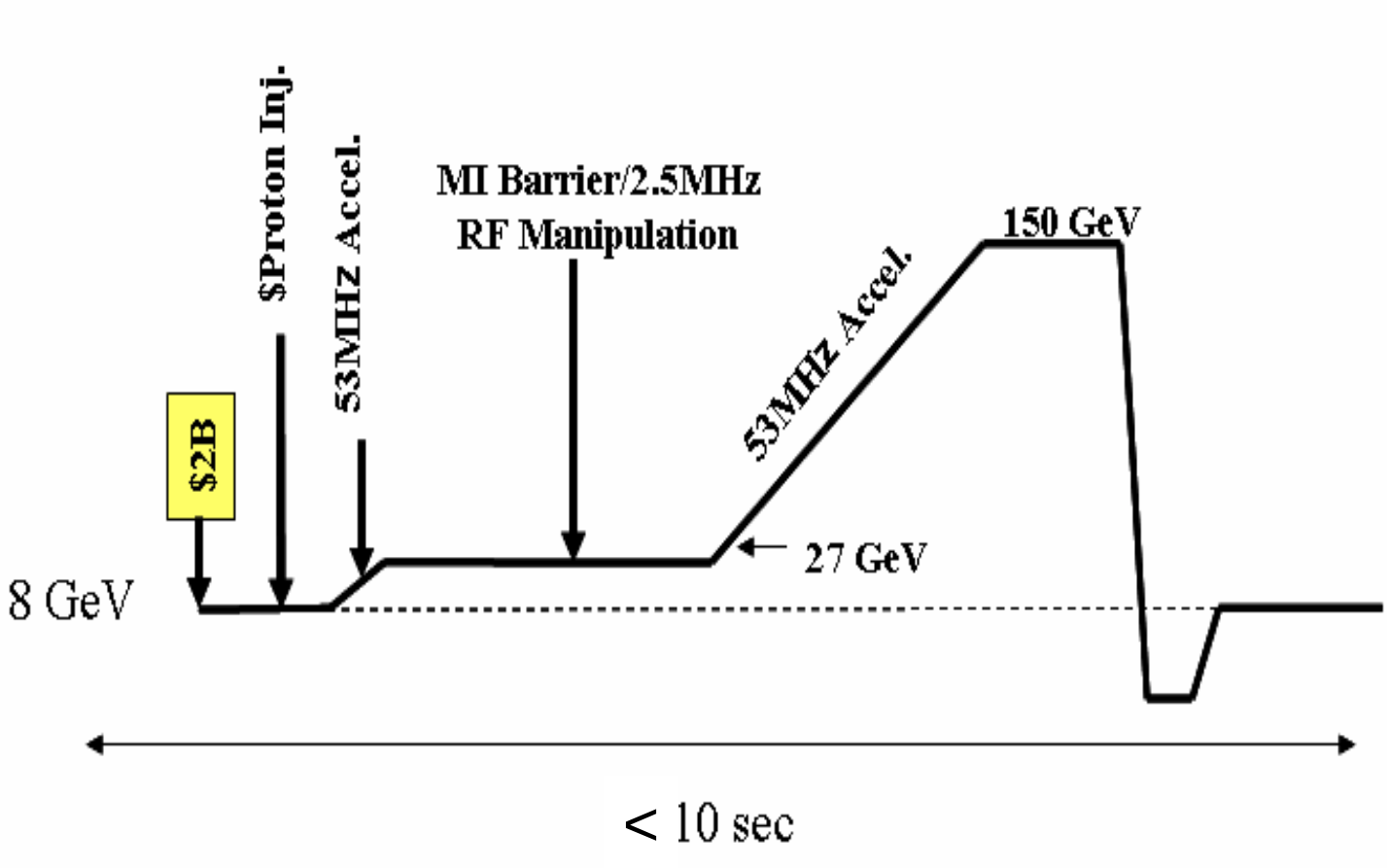
Adiabatic $V(53MHz)_{min}$

Bucket area :

$$\varepsilon_l = T_2 \Delta E_b + \frac{8\pi|\eta|}{3\omega_o \beta^2 E_o e V_{rf}} \left[\frac{\Delta E_b}{2} \right]^3$$

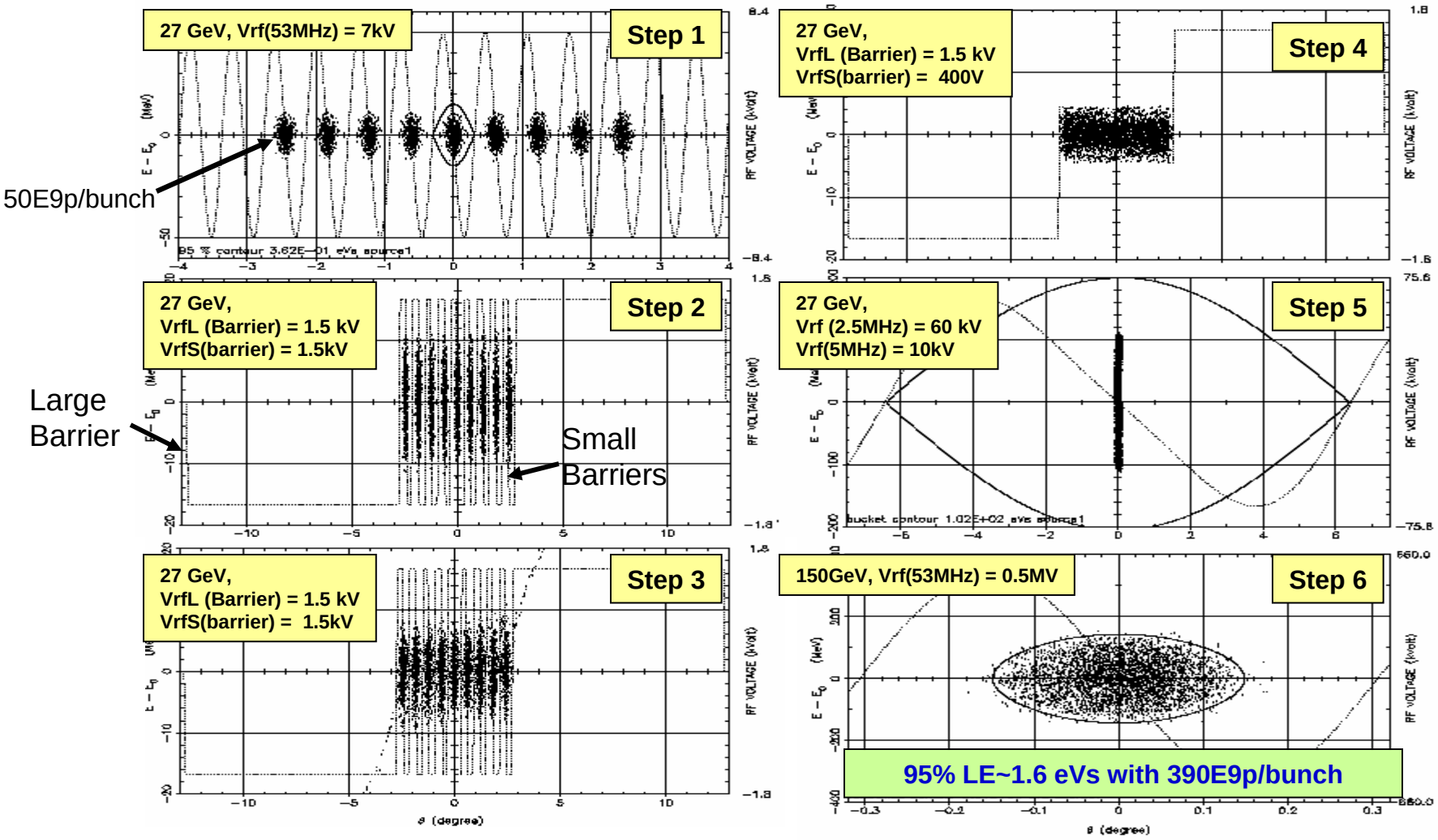
- η is phase slip factor,
- E_o is synchronous energy,
- $\omega_o = 2\pi f_{rev}$ with f_{rev} = beam circulation frequency.

MI Acceleration Ramp



Barrier Bucket Scheme -1

ESME simulations; (LE(inj) = 0.15 eVs)



With 11 bunch injection ~80% beam survive in about 1.7 eVs

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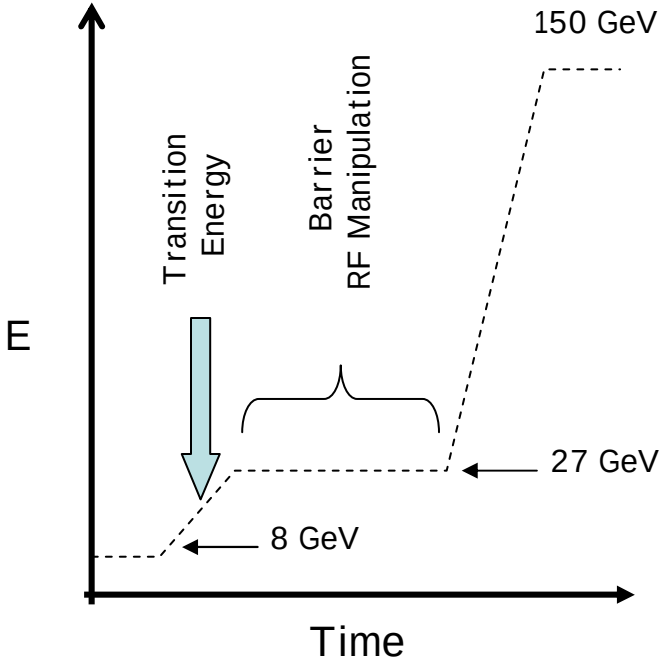
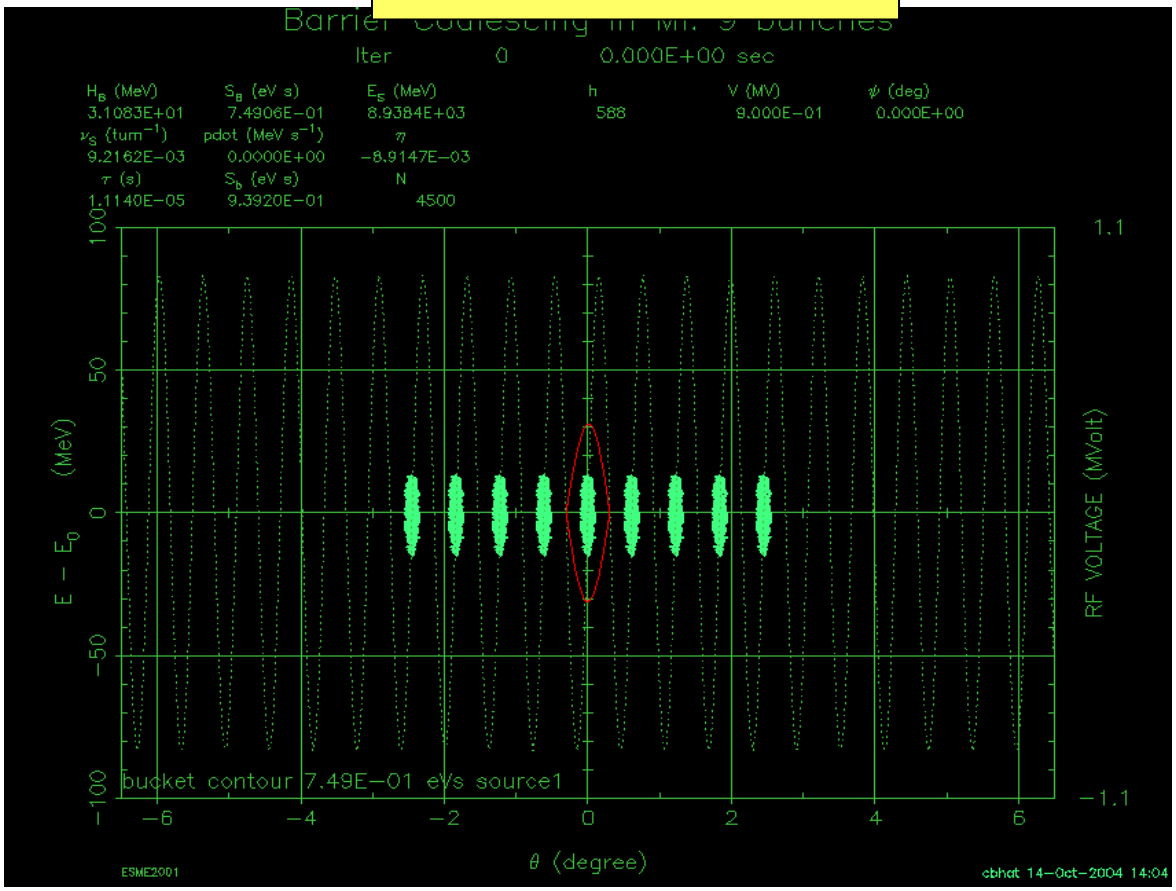
MI Barrier Coalescing Scheme-1 (Cont.)

MI Magnet Ramp

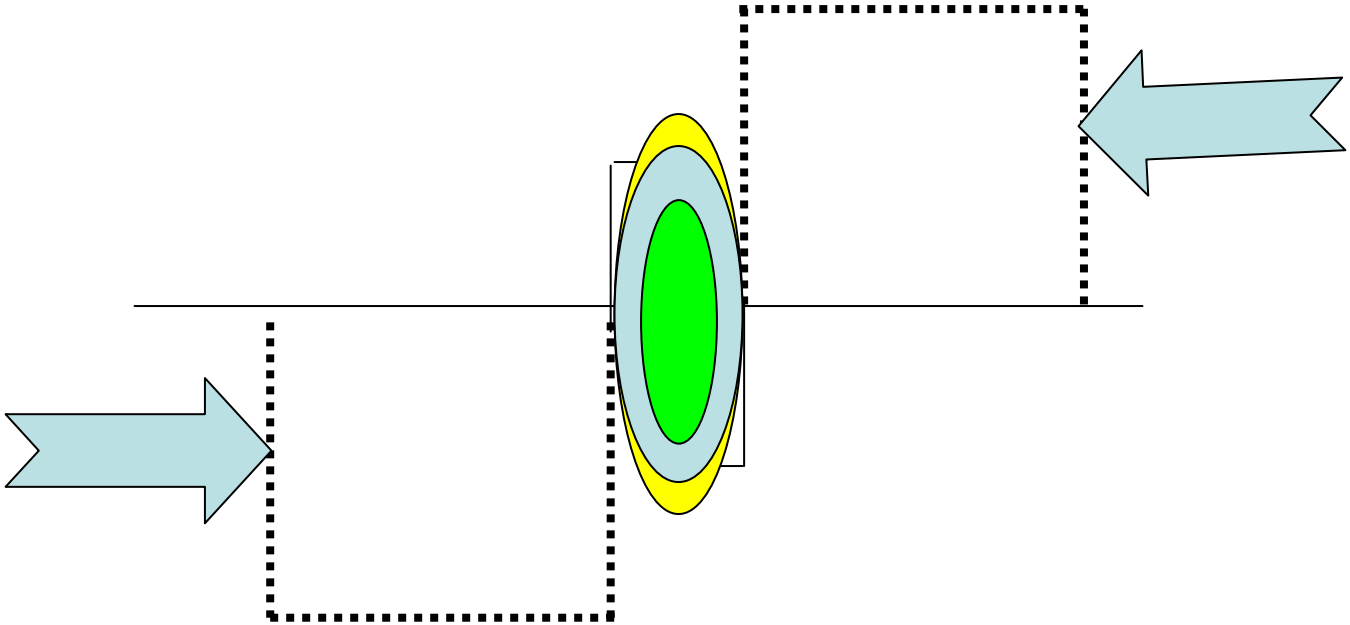


ESME simulations



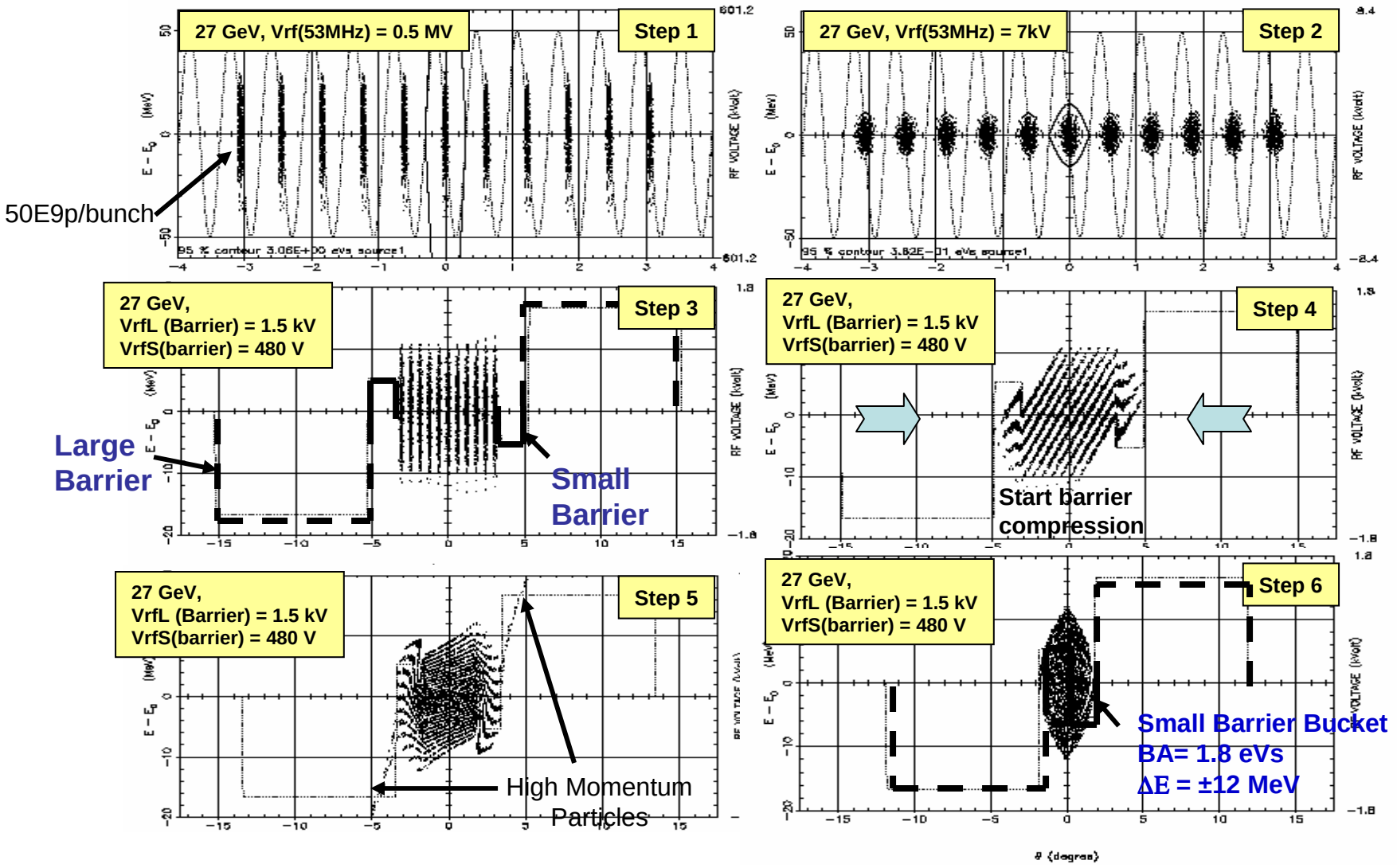
By this method one can send ~300E9 protons/1.5 eVs/ bunches for collider shots

Principle of the Barrier Bucket Scheme-2



Barrier Bucket Scheme -2

ESME simulations; (LE(inj) = 0.15 eVs)



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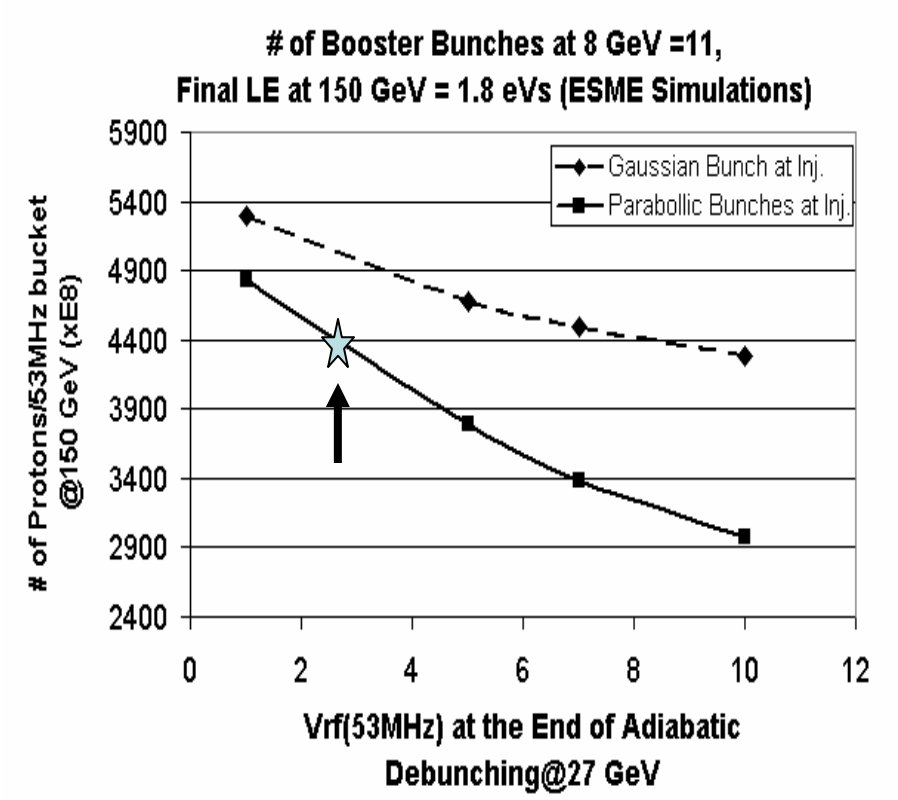
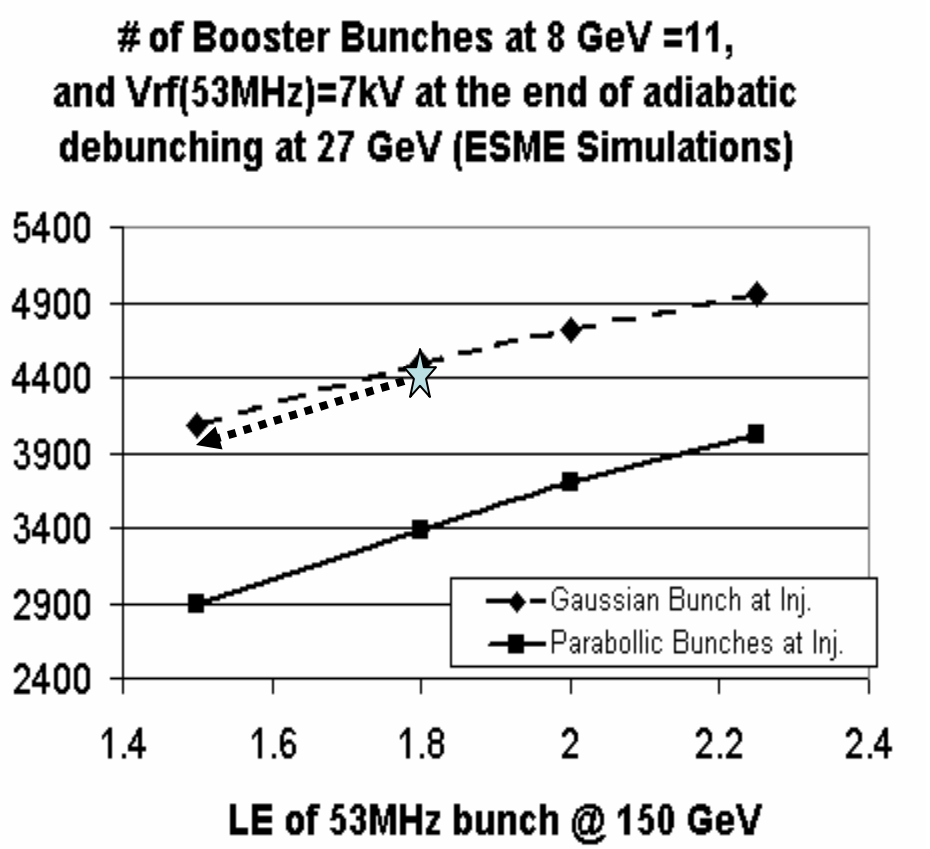
Simulations Continued

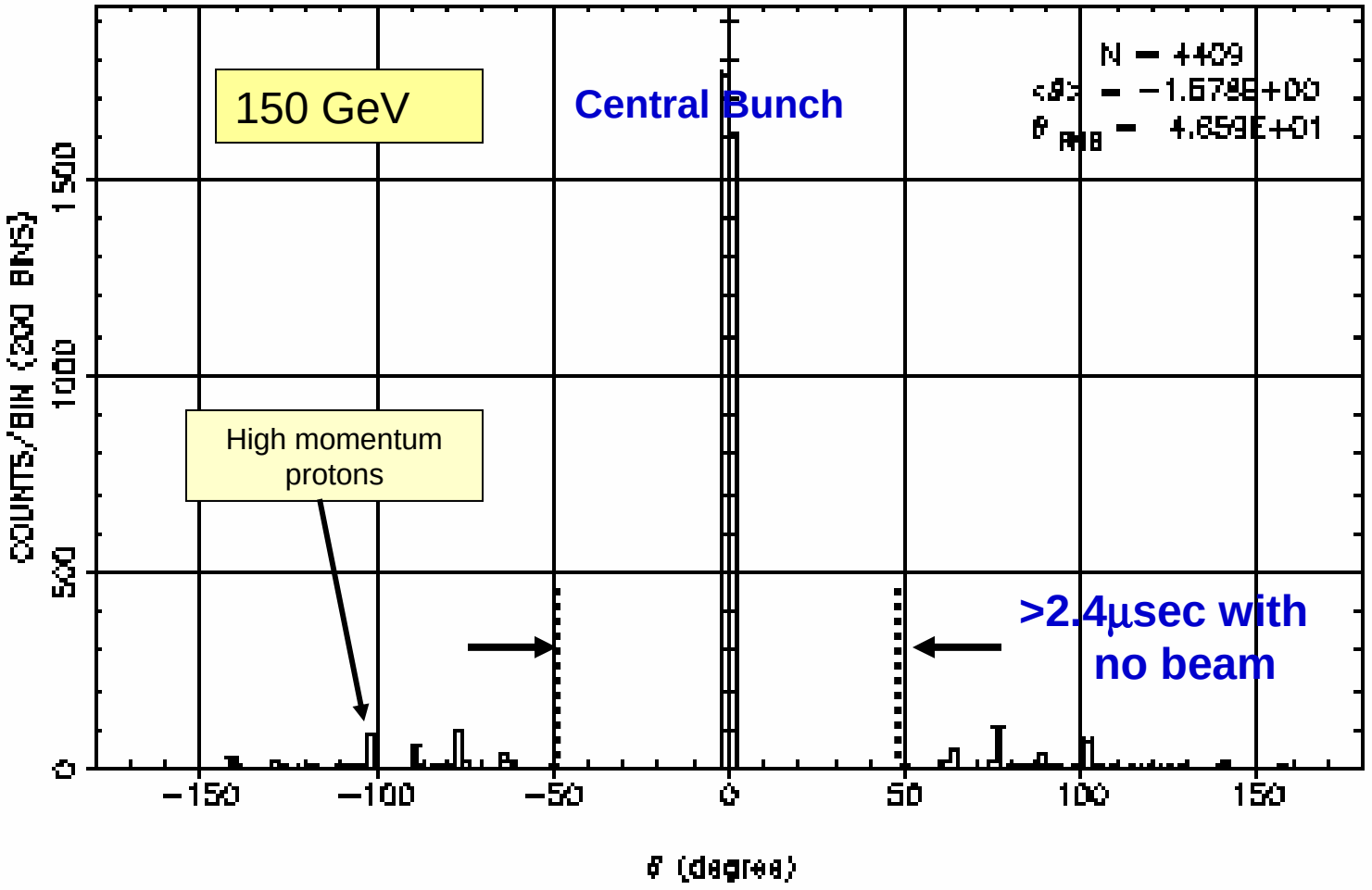
(Barrier Compression Method)





If number of Booster bunches is changed from 11 to 15 then bunch intensity goes up by 7%

Central Bunch and the rest



Space-Charge and Wake Field Effects

- Space-charge: Bunch space charge density is higher than in the present coalescing scheme but four times smaller than that in the stacking cycle (without slip-stacking) → Not a problem

- Longitudinal microwave instability: Well below Keil-Schnell limit for bunches up to 600E9ppb
  → Not a problem

- Cavity Beam-loading effects from 2.5MHz and 53MHz rf system are adequately compensated for bunch intensity ~400E9ppb→ Not a problem

- Barrier RF system: 50Ω x3 =150 Ω system gives about -1.2V potential distortion. This can be corrected → Not a problem

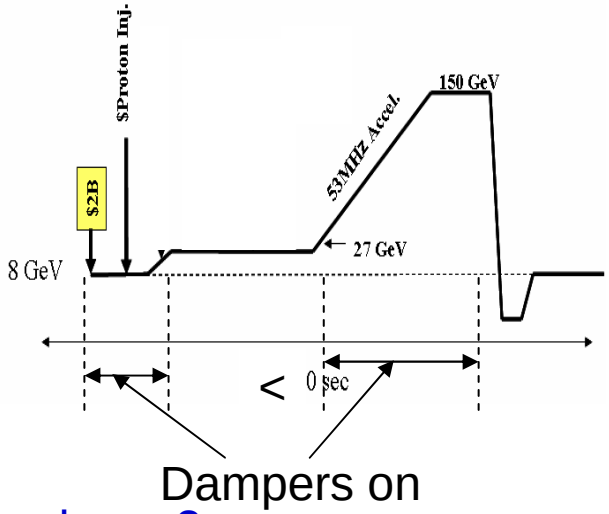
Detailed simulations are in progress

Implementation

- Hardware: Longitudinal Damper Cavities in MI ← Already exists

  Ref: D. Wildman (Private Comm., 2002)

- Using Damper System as Barrier RF system: P. Adamson recently made modifications to the longitudinal damper software to turn-on and off on any acceleration cycle. So we use the system for damping 53MHz longitudinal oscillations from 8-27 GeV and 27-150 GeV, and at 27 GeV use the system as a barrier rf system to meet our requirements. (Scheme-1 is quite straight forward)



- How much time does one need to implement this scheme?

  Estimate: 2 hr/shift x 6 shifts x 10sec/60sec super cycle

What do we gain in terms of ppbar luminosity?

- Can choose proton bunch intensity in the range of 270-400E9 (or more) keeping the same transverse emittances & LE< 2eVs to the Tevatron.

  ←~20% increase in ppbar luminosity

- Typically proton transverse emittance to the Tevatron at 150GeV is about 15-16π-mm-mr. This arises mainly from the Booster (high intensity coalesced bunches in the present scheme implies large number of Booster turns). With the scheme proposed here, one can possibly reduce the transverse emittance to about 10-12π-mm-mr (still higher than pbar transverse emittance) by using less Booster turns and more bunches.

  ← Additional ~20% increase in ppbar luminosity.

Summary

- I have proposed two promising schemes which use MI barrier rf systems to achieve proton bunch intensities in excess of 300E9 with LE<1.8 eVs for Tevatron shots.
- With proton bunch intensity increased from 225E9ppb to 270E9ppb with LE decreased from 3 eVs to 2 eVs at collision the peak luminosity should increase by about 20%.